**APPLY BASIC EXERCISE SCIENCE TO EXERCISE INSTRUCTION**

**THEORY WORKBOOK**

**VCE / VET**

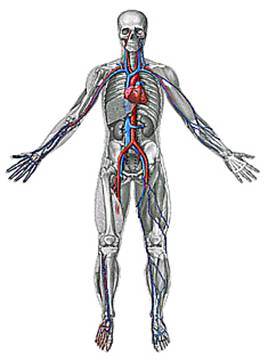
**FITNESS FOCUS – BUNDLE ONE**

**Competencies addressed in this workbook task**

* **SRFFIT005B:** 
  + **Apply Basic Exercise Science to Exercise Instruction**
    - **Element Two – Relate the functioning of the cardio-respiratory system to exercise instruction.**
  + Identify and explain the structure and function of the various parts of the ***cardio–respiratory system***, related to exercise to clients
  + Relate the process of transport and exchange of oxygen and carbon dioxide during exercise to fitness outcomes when instructing clients
  + Measure client heart rates and blood pressure responses during ***submaximal aerobic activity*** and used to set training loads to target specific client energy system involvement
  + Use ratings of perceived exertion during ***submaximal aerobic activity***, muscle endurance activities, lactate endurance and maximal strength activities to measure and adjust the work intensity of clients
  + Compare the oxygen demands for various fitness activities
  + Explain the physiological adaptations of the cardio–respiratory system as a result of fitness training to clients
  + Recognise and use symptoms and effects of specific muscular fatigue and blood lactate accumulation during muscle endurance activities to adjust exercise intensity

**The Cardio-Respiratory System**

* To maintain a constant state of efficient operation, the body needs to have support systems.
* The cardio-respiratory system comprises the **cardiovascular** and **respiratory** (lungs) systems.
* Together they provide the tissues with oxygen, nutrients, protective agents, and a means to remove waste by-products.
* The cardiovascular system is composed of the heart, blood, and blood vessels.



1. Label the diagram above 4 marks

**Circulatory System: The Circle of Blood**

On average, your body has about 5 litres of blood continually traveling through it by way of the circulatory system. The heart, the lungs, and the [blood vessels](http://www.fi.edu/learn/heart/vessels/vessels.html) work together to form the circle part of the circulatory system. The pumping of the heart forces the blood on its journey.

The body's circulatory system really has three distinct parts: [pulmonary circulation](http://www.fi.edu/learn/heart/systems/pulmonary.html), [coronary circulation](http://www.fi.edu/learn/heart/systems/coronary.html), and [systemic circulation](http://www.fi.edu/learn/heart/systems/systemic.html). Or, the lungs (pulmonary), the heart (coronary), and the rest of the system (systemic). Each part must be working independently in order for them to all work together.

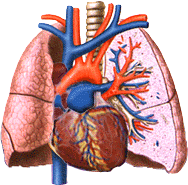
**Systemic Circulation: It's All Throughout the Body**

Systemic circulation supplies nourishment to all of the tissue located throughout your body, with the exception of the heart and lungs because they have their own systems. Systemic circulation is a major part of the overall [circulatory system](http://www.fi.edu/learn/heart/systems/circulation.html).

The [blood vessels](http://www.fi.edu/learn/heart/vessels/vessels.html) (arteries, veins, and capillaries) are responsible for the delivery of oxygen and nutrients to the tissue. Oxygen-rich blood enters the blood vessels through the heart's main artery called the aorta. The forceful contraction of the heart's left ventricle forces the blood into the aorta which then branches into many smaller arteries which run throughout the body. The inside layer of an artery is very smooth, allowing the blood to flow quickly. The outside layer of an artery is very strong, allowing the blood to flow forcefully. The oxygen-rich blood enters the capillaries where the oxygen and nutrients are released. The waste products are collected and the waste-rich blood flows into the veins in order to circulate back to the heart where [pulmonary circulation](http://www.fi.edu/learn/heart/systems/pulmonary.html) will allow the exchange of gases in the lungs.

During systemic circulation, blood passes through the kidneys. This phase of systemic circulation is known as renal circulation. During this phase, the kidneys filter much of the waste from the blood. Blood also passes through the small intestine during systemic circulation. This phase is known as portal circulation. During this phase, the blood from the small intestine collects in the portal vein which passes through the liver. The liver filters sugars from the blood, storing them for later.

**Pulmonary Circulation: It's All in the Lungs**



Pulmonary circulation is the movement of blood from the heart, to the lungs, and back to the heart again. This is just one phase of the overall [circulatory system](http://www.fi.edu/learn/heart/systems/circulation.html).

The veins bring waste-rich blood back to the heart, entering the right atrium throughout two large veins called vena cavae. The right atrium fills with the waste-rich blood and then contracts, pushing the blood through a one-way valve into the right ventricle. The right ventricle fills and then contracts, pushing the blood into the pulmonary artery which leads to the lungs. In the lung capillaries, the exchange of carbon dioxide and oxygen takes place. The fresh, oxygen-rich blood enters the pulmonary veins and then returns to the heart, re-entering through the left atrium. The oxygen-rich blood then passes through a one-way valve into the left ventricle where it will exit the heart through the main artery, called the aorta. The left ventricle's contraction forces the blood into the aorta and the blood begins its journey throughout the body.

The one-way valves are important for preventing any backward flow of blood. The circulatory system is a network of one-way streets. If blood started flowing the wrong way, the blood gases (oxygen and carbon dioxide) might mix, causing a serious threat to your body.

You can use a stethoscope to hear pulmonary circulation. The two sounds you hear, "lub" and "dub," are the ventricles contracting and the valves closing.

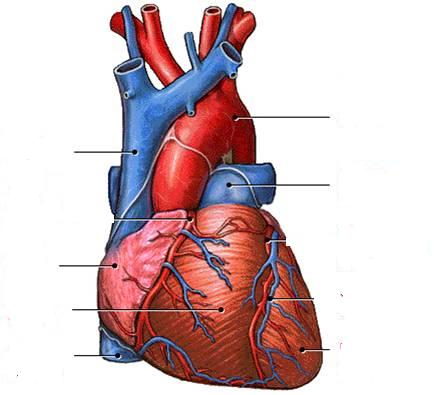
**Coronary Circulation: It's All in the Heart**

While the circulatory system is busy providing oxygen and nourishment to every cell of the body, let's not forget that the heart, which works hardest of all, needs nourishment, too. Coronary circulation refers to the movement of blood through the tissues of the heart. The circulation of blood through the heart is just one part of the overall [circulatory system](http://www.fi.edu/learn/heart/systems/circulation.html).

**Heart**

* A muscular pump that rhythmically contracts to push blood throughout the body
* Heart muscle is termed ***cardiac muscle*** and has characteristics similar to skeletal muscle.
  + Cardiac muscle contraction is involuntary.

1. Label the diagram below



6 marks

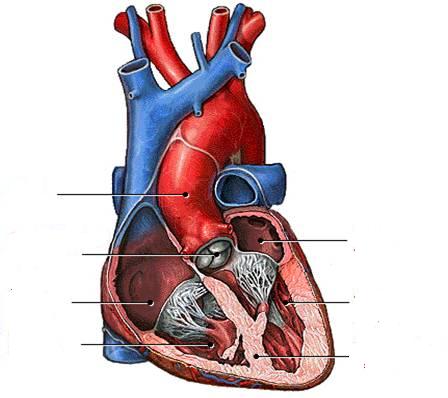
The heart is one of the most important organs in the entire human body. It is really nothing more than a pump, composed of muscle which pumps blood throughout the body, beating approximately 72 times per minute of our lives. The heart pumps the blood, which carries all the vital materials which help our bodies function and removes the waste products that we do not need. For example, the brain requires oxygen and glucose, which, if not received continuously, will cause it to loose consciousness. Muscles need oxygen, glucose and amino acids, as well as the proper ratio of sodium, calcium and potassium salts in order to contract normally. The glands need sufficient supplies of raw materials from which to manufacture the specific secretions. If the heart ever ceases to pump blood the body begins to shut down and after a very short period of time will die.

The heart is essentially a muscle (a little larger than the fist). Like any other muscle in the human body, it contracts and expands. Unlike skeletal muscles, however, the heart works on the "All -or-Nothing Law". That is, each time the heart contracts it does so with all its force. In skeletal muscles, the principle of "gradation" is present. The pumping of the heart is called the *Cardiac Cycle*, which occurs about 72 times per minute. This means that each cycle lasts about eight-tenths of a second. During this cycle the entire heart actually rests for about four-tenths of a second.

The walls of the heart are made up of three layers, while the cavity is divided into four parts. There are two upper chambers, called the right and left *atria*, and two lower chambers, called the right and left *ventricles*. The Right Atrium, as it is called, receives blood from the upper and lower body through the *superior vena cava* and the *inferior vena cava*, respectively, and from the heart muscle itself through the *coronary sinus*. The right atrium is the larger of the two atria, having very thin walls. The right atrium opens into the right ventricle through the *right atrioventicular valve* (tricuspid), which only allows the blood to flow from the atria into the ventricle, but not in the reverse direction. The right ventricle pumps the blood to the lungs to be reoxygenated. The left atrium receives blood from the lungs via the four *pulmonary veins*. It is smaller than the right atrium, but has thicker walls. The valve between the left atrium and the left ventricle, the *left atrioventicular valve* (bicuspid), is smaller than the tricuspid. It opens into the left ventricle and again is a one way valve. The left ventricle pumps the blood throughout the body. It is the *Aorta*, the largest artery in the body, which originates from the left ventricle.

The Heart works as a pump moving blood around in our bodies to nourish every cell. Used blood, that is blood that has already been to the cells and has given up its nutrients to them, is drawn from the body by the right half of the heart, and then sent to the lungs to be reoxygenated. Blood that has been reoxygenated by the lungs is drawn into the left side of the heart and then pumped into the blood stream. It is the atria that draw the blood from the lungs and body, and the ventricles that pump it to the lungs and body. The output of each ventricle per beat is about 70 ml, or about 2 tablespoons. In a trained athlete this amount is about double. With the average heart rate of 72 beats per minute the heart will pump about 5 litres per ventricle, or about 10 litres total per minute. This is called the cardiac output. In a trained athlete the total cardiac output is about 20 litres. If we multiply the normal, non-athlete output by the average age of 70 years, we see that the cardiac output of the average human heart over a life time would be about 1 million litres.

1. Label the heart diagram below 7 marks

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**Blood**

The average adult has about five litres of blood living inside of their body, coursing through their vessels, delivering essential elements, and removing harmful wastes. Without blood, the human body would stop working.

Blood is the fluid of life, transporting oxygen from the lungs to body tissue and carbon dioxide from body tissue to the lungs. Blood is the fluid of growth, transporting nourishment from digestion and hormones from glands throughout the body. Blood is the fluid of health, transporting disease fighting substances to the tissue and waste to the kidneys.



Because it contains living cells, blood is alive. [Red blood cells](http://www.fi.edu/learn/heart/blood/red.html) and [white blood cells](http://www.fi.edu/learn/heart/blood/white.html) are responsible for nourishing and cleansing the body. Since the cells are alive, they too need nourishment.

Vitamins and Minerals keep the blood healthy. The blood cells have a definite life cycle, just as all living organisms do. Approximately 55 percent of blood is [plasma](http://www.fi.edu/learn/heart/blood/plasma.html), a straw-coloured clear liquid. The liquid plasma carries the solid cells and the [platelets](http://www.fi.edu/learn/heart/blood/platelet.html) which help blood clot. Without blood platelets, you would bleed to death.

When the human body loses a little bit of blood through a minor wound, the platelets cause the blood to clot so that the bleeding stops. Because new blood is always being made inside of your bones, the body can replace the lost blood. When the human body loses a lot of blood through a major wound, that blood has to be replaced through a blood transfusion from other people.

But everybody's blood is not the same. There are four different [blood types](http://www.fi.edu/learn/heart/blood/types.html). Plus, your blood has [Rh factors](http://www.fi.edu/learn/heart/blood/rh.html) which make it even more unique. Blood received through a transfusion must match your own. Patients who are scheduled to have major surgery make [autologous blood donations](http://www.bloodbook.com/autolog-1.html) (donations of their own blood) so that they have a perfect match.

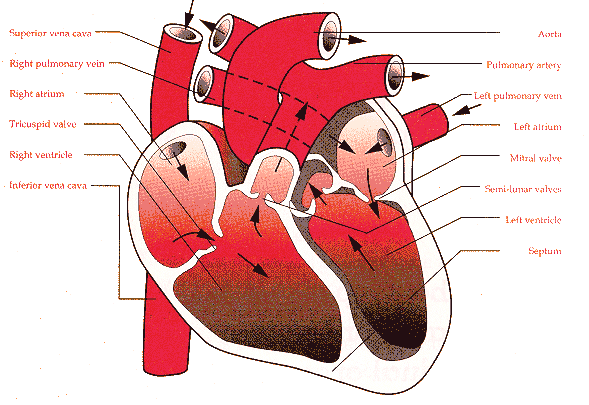
**Blood Pressure**

The function of the heart is to circulate blood around the body. The heart comprises of four chambers:

* Right Atrium
* Left Atrium
* Right Ventricle
* Left Ventricle

Functionally the heart comprises of two pumps:

* The right atrium receives blood from the body (de-oxygenated blood) and the right ventricle pumps it into the lungs for aeration (removal of carbon dioxide and add oxygen).
* The left atrium receives the oxygenated blood from the lungs and the left ventricle pumps it around the body.



**Blood Pressure**

The cardiac cycle (heartbeat) consists of cardiac muscle contraction (systole) and cardiac muscle relaxation (diastole).

Blood pressure represents the force (pressure) exerted by blood against the arterial walls during a cardiac cycle. Systolic blood pressure, the higher of the two pressure measurements, occurs during ventricular contraction (systole) as the heart pumps blood into the aorta.

After systole, the ventricles relax (diastole), arterial pressure declines and the heart refills with blood. The lowest pressure reached during ventricular relaxation represents the diastolic blood pressure.

Normal systolic blood pressure in an adult varies between 110 and 140 mm Hg, and diastolic pressure varies between 60 and 90 mm Hg.

**Blood Pressure Classification**

|  |  |  |
| --- | --- | --- |
| Systolic(mm Hg) | Diastolic(mm Hg) | Classification |
| <130 | <85 | Normal |
| 130-139 | 85-89 | High Normal |
| 140-159 | 90-99 | Hypertension (stage 1) |
| 160-179 | 100-109 | Moderate Hypertension (stage 2) |
| 180-209 | 110-119 | Severe Hypertension (stage 3) |
| >209 | >119 | Very Severe Hypertension (stage 4) |

**Heart Rate**

The resting heart rate for the average person is between 70 and 90 beats per minute (bpm). The term tachycardia is applied to a rapid heart rate (over 100 bpm) and the term bradycardia indicates a slow heart rate (less than 50 bpm). Endurance athletes may have a resting heart rate of less than 50 bpm.

**Cardiac Output**

This is the amount of blood pumped from your heart and is calculated by multiplying heart rate by stroke volume (the amount of blood ejected by the heart in each beat). An athlete will have a lower resting heart rate and a larger stroke volume than a non-athlete. The cardiac output for an athlete is approx. 35 litres while that for the non-athlete is 22 litres.

**Physiological adaptations to aerobic training**

When an athlete begins to undertake regular aerobic training the body begins to adapt physically to the demands placed upon it. This makes the body more efficient and capable of more work. To explore these adaptations further, click on the appropriate heading below.

[**Resting heart rate**](http://www.hsc.csu.edu.au/pdhpe/core2/aerobic/4-2/4.2.3.1Restingheartrate.html) is the minimum number of beats required by the heart to provide for the basic needs of the body at rest.

[**Stroke volume**](http://www.hsc.csu.edu.au/pdhpe/core2/aerobic/4-2/4.2.3.2Strokevolume.html) is the amount of blood pumped out of the heart during each contraction.

[**Cardiac output**](http://www.hsc.csu.edu.au/pdhpe/core2/aerobic/4-2/4.2.3.3Cardiacoutput.html) is the amount of blood pumped out of the heart each minute.

[**Oxygen uptake**](http://www.hsc.csu.edu.au/pdhpe/core2/aerobic/4-2/4.2.3.4Oxygenuptake.html) is the amount of oxygen that enters the body in a minute.

[**Ventilation rates**](http://www.hsc.csu.edu.au/pdhpe/core2/aerobic/4-2/4.2.3.5Ventilationrates.html) is the total amount of air passing in and out of the lungs within a minute.

[**Blood pressure**](http://www.hsc.csu.edu.au/pdhpe/core2/aerobic/4-2/4.2.3.6BloodPressure.html) (BP) consists of two components, systolic and diastolic.

* Systolic BP is the pressure within the arteries during ventricular contraction.
* Diastolic BP is the pressure within the arteries during ventricular filling.

**Lung capacity** and **haemoglobin level** are not covered in detail in this section. Training will increase lung capacity only slightly, whilst haemoglobin levels are largely determined by genetic factors. That is, the number of slow or fast twitch fibres which the individual has is determined at birth and cannot be changed to any large extent through training. It is known that athletes with slow-twitch muscles tend to have higher levels of haemoglobin and can therefore absorb higher amounts of oxygen.

1. Write the equation for calculating cardiac output

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1 mark

1. Write the equation for calculating estimated maximum heart rate

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1 mark

1. List the 4 chambers of the heart

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1 mark

1. Your client has a blood pressure reading of systolic 160, diastolic 110. What classification of hypertension is your client? What would you recommend and why?

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5 marks

1. Give a brief definition of each of the following:

Heart \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Artery \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Vein \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Capillary\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Platelets\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Red Blood Cells\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Blood \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Systolic blood pressure\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Diastolic blood pressure\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

9 marks

1. List and briefly define the three types of circulation in the body

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6 marks

1. List two short term effects of exercise on the cardiovascular system.

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2 marks

1. List four long term effects of exercise on the cardiovascular system

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4 marks

1. Explain why a lower resting heart rate would result from aerobic training.

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4 marks

1. Explain why you would recommend exercise that extends and develops the cardiovascular system to your clients. What are the health benefits?

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5 marks

**Respiratory System**

**Respiratory System**

The respiratory system comprises of the nose, mouth, throat, larynx, trachea, bronchi and lungs. The function of the respiratory system is to facilitate gaseous exchange to take place in the lungs and tissue cells of the body.

|  |  |
| --- | --- |
| Oxygen is required by cells in the body to allow various metabolic reactions to take place and to produce energy and is therefore essential to life.  The respiratory system may be defined as the organs and tissues through which air is passed into and out of the body to allow the necessary gaseous exchanges to take place.  External respiration is the means by which oxygen from the air passes into the blood stream for transportation to the tissue cells and carbon dioxide is collected and transferred back to the lungs and expelled from the body.  Internal respiration involves the vital chemical activities that take place in every living cell requiring oxygen and glycogen to combine and release energy, water and carbon dioxide. | **Organs of the respiratory system**  Respiratory system |

The normal rate of inspiration and expiration, the respiration rate, is about 16 times a minute in an adult.

**Composition of Air**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Breathed In | Gas | Breathed Out |
|  | 21% | Oxygen | 17% |
|  | 78% | Nitrogen | 78% |
|  | 0% | Carbon Dioxide | 4% |
|  | 1% | Tracer Gases | 1% |

**Effect of exercise on the respiratory system**

In the Cardiovascular system, the benefits of exercise were discussed in relation to the improved functioning of the heart and the lowering of blood pressure. Combined with increased maximum oxygen consumption ([VO2 max](http://www.brianmac.co.uk/vo2max.htm)), or lung capacity, these are all vital contributors to being fit and healthy.

An athlete who has not properly trained their cardiovascular system is likely to incur other injuries more easily by the rapid onset of fatigue and the consequent lowering of motivation and mental awareness. For anyone competing at varying altitudes, they must allow themselves a considerable period to acclimatise before an event. Even climbing to a moderate [altitude](http://www.brianmac.co.uk/environ.htm) decreases the maximum uptake by 7% to 8% due to the change in atmospheric pressure. This decrease in oxygen being supplied to the muscles may decrease performance by 4 to 8% depending on the duration of competition, a considerable disadvantage at the finish line.

Even the athlete who prepares and acclimatises well may still not match natives of high altitude areas such as the Andes, who have a larger chest capacity, more alveoli, larger capillary beds and higher red blood cell count. Since people may suffer from altitude sickness when moving from low to high altitudes, sufficient time must also be allowed for these symptoms to disappear before starting intensive training.

**Inspiration and Expiration**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| bullet | Inspiration:  breathing in (a.k.a., inhalation; *not* motivation)   |  |  | | --- | --- | | bullet | Always an active process | | bullet | Caused by muscular contraction, mainly of the   |  |  | | --- | --- | | bullet | diaphragm | | bullet | intercostal muscles | | |
| bullet | Expiration:  breathing out (a.k.a., exhalation; *not* dying!)   |  |  | | --- | --- | | bullet | Typically a passive process | | bullet | mainly caused by   |  |  | | --- | --- | | bullet | elastic recoil of the diaphragm | | bullet | relaxation of the intercostal muscles | | |

**Inspiration**

**How is it possible to get air inside of our bodies?**

    If I want to get air inside a room, I would have to do a few things.   First of all, I'd have to have a passageway for the air-- like an open door or window.  Then I would need some force to push or draw the air into the room.   The air could be pushed into the room from outside.  For example, a fan located in the hall outside of the room could be used to push the air into the room through the door, or the wind outside could push air into the room through the window.   The air could also be drawn into the room from inside.  For example, a fan could be positioned in front of the window inside the room, and draw air in through the window.

    Well, in our bodies, we have a clear passageway for the air, from outside into our nasal cavity (or mouth), to our pharynx, trachea, bronchi, bronchioles, and eventually into the alveoli.  We have to get the air into our alveoli, because that is where all gas exchange will occur.

    The other thing we need is a way to push or draw air into that passageway.  We can't sit in front of a fan all day!  We certainly have no way to push it in (or you'd see something outside of our noses all day), so there has to be a way to draw it in.  You may now be thinking about how something could act like a fan within our bodies, drawing air into our alveoli... at least I hope that is what you are thinking.  It works something like that.

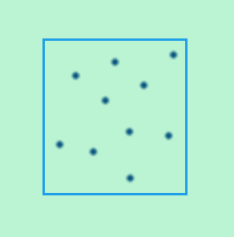
    Think back to the fan example.  A fan is a force on the air.   When it forces the air to move, we can talk about the fan increasing the air pressure on the air it moves.  So, what we really need is a way to create air pressure to draw the air into our bodies.  Right?

    The air in our world sits at a rather constant pressure, called the **atmospheric pressure**, of 760 mm Hg.  Note that air pressure, just like blood pressure, is measured in units of "mm Hg."  If we want to draw air into our bodies, we have to be able to make our respiratory tract have a *lower* pressure than 760 mm Hg.  It has to be lower, because all items tend to move from high pressure toward low pressure without any extra energy needed.

    Therefore, the entire question of how we inhale can be narrowed down to the more specific question: "how do we decrease the pressure within our respiratory tract?"  Keep in mind that we have to do this over and over, since breathing is cyclical.

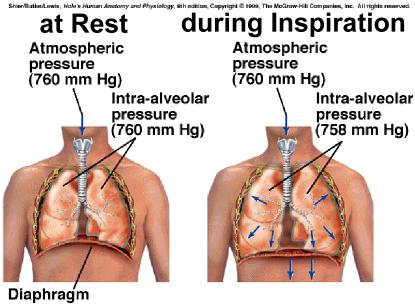
**How do we decrease the pressure within our respiratory tract?**

    To understand this, you may need to picture what air pressure really is.  Air is made up of many molecules.  All molecules are in constant, random motion.  As the molecules move around, the amount that they bang against each other and against any container that they are in is their pressure.  I have tried to demonstrate this for you in the animation below.

At first, the air molecules are just moving around normally.  Notice that their movement is pretty random (at least I tried to make it random).  Then, I have gone ahead and changed the container within which they are moving.  I made the container larger.  Once the container is larger, the molecules, still moving at the same rate, are now less likely to bump into each other or into the walls of the container.  You should at least be able to see that the air molecules tend to be more spread out when the container is larger.  Less bumping around of air molecules reflects less pressure of the air.

    This is the trick, then.  In order to decrease the pressure within our respiratory tract, we have to expand our container.  Our container is basically our thorax.  If we can expand our thorax, the air pressure within our thoracic cavity will fall, and air will rush into our respiratory tract.

    The **diaphragm** is our primary means to increase our thoracic cavity (to decrease the air pressure in our thoracic cavity).  The diaphragm lies at the base of the thorax, separating the thoracic cavity from the abdominal cavity.  The diaphragm is a sheet of skeletal muscle; it can contract under automatic or voluntary control.  At rest, however, this sheet of muscle is not flat; instead, it has a curved shape to it.  When you view the diaphragm from anterior or from the side, you can see that the diaphragm is curved.  Therefore, when the diaphragm contracts, it flattens out.  This flattening out of the diaphragm, the inferior aspect of the thorax, causes the size of the thorax to increase.



**Other muscles can help to expand the thoracic cavity**

    The **external intercostal muscles** of the thorax are also often involved in inspiratory breathing.  When these muscles contract, they act to raise the ribs and elevate the sternum.  You see, the contraction of the diaphragm increased the thoracic volume by lowering the bottom border of the thorax, while the external intercostal muscles increase thoracic volume by raising the top border of the thorax.

    For really deep inspiratory breaths, like before you dive underwater, the external intercostal muscles contract more, and other muscles can also participate.  The pectoralis minor muscles and the sternocleidomastoid muscles can pull on the rib cage and sternum more, to raise it and draw it out further.

1. Complete the following:

Pressure increases -> Volume \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Volume increase -> Pressure \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 1 mark

1. Considering the principles involved in inspiration and expiration, explain why would you instruct a client to stand up rather than crouching over when recovering their breath from an exhaustive aerobic exercise.

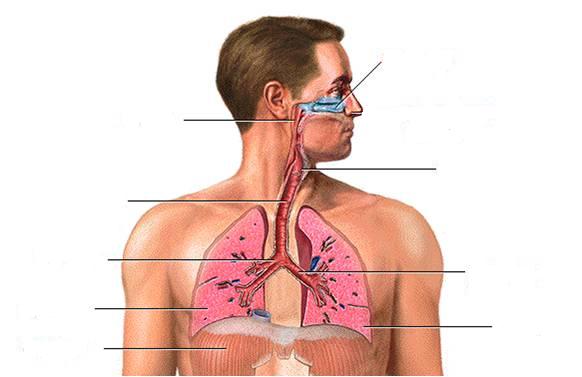
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3 marks

1. Label the diagram of the respiratory system below



9 marks

1. Define VO2 Max

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1 mark

1. List two benefits of exercise on the respiratory system

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2 marks

1. Briefly define the respiratory system

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2 marks

**Muscle Fatigue**

We use the term fatigue to describe a general feeling of the overall effects of an exercise on the body or the inability to continue with an exercise. So what causes this sensation of fatigue? The reason has to do with several factors including the availability of fuel for the muscles and the mechanism of hydrogen ions and calcium in muscle cell action.

**Fuel**

Muscles require ATP (adenosine triphosphate) as an energy source. During intense activity we rely on the anaerobic pathway but this has a limited store (ATP/CP pathway approximately 10 seconds and the Anaerobic Lactic pathway approximately 2 minutes). The aerobic pathway produces ATP copiously (with the breakdown of glucose and glycogen) and requires oxygen, carried by the blood, to support the process. The cardiovascular system is limited in its ability to deliver blood and oxygen to the working muscles.

**Hydrogen ions**

The breakdown of glucose or glycogen produces lactate and hydrogen ions. If insufficient oxygen is available to the working muscles then hydrogen ion concentrations increase and the blood and muscle become acidic. This acidic environment start to block the nerve signals from the brain to muscle fibres so the legs begin to feel heavy and we slow down in order to allow more oxygen to get to the working muscles.

**Calcium**

One of the functions of calcium is to help control muscle contractions. Researchers at the Columbia University Medical Centre conducted a study which found that muscle fatigue after long intense exercise may be caused by tiny leaks of calcium inside muscle cells. The researchers found that after extended high intensity exercise, 3 hours of cycling by experienced cyclists, small channels in the athlete's muscle cells were leaking calcium. This calcium leak weakens muscle contraction and stimulates an enzyme that attacks muscle fibres resulting in muscle fatigue. These calcium leaks stopped after a few days rest.

**Lactic Acid**

The expression "lactic acid" is used most commonly by athletes to describe the intense pain felt during exhaustive exercise, especially in events like the 400 metres and 800 metres. When energy is required to perform exercise, it is supplied from the breakdown of Adenosine Triphosphate (ATP). The body has a limited store of about 85 grms of ATP and would use it up very quickly if we did not have ways of resynthesising it. There are [three systems that produce energy](http://www.brianmac.co.uk/energy.htm) to resynthesise ATP: ATP-PC, lactic acid and aerobic.

The lactic acid system is capable of releasing energy to resynthesise ATP without the involvement of oxygen and is called anaerobic glycolysis. Glycolysis (breakdown of carbohydrates) results in the formation of pyruvic acid and hydrogen ions (H+). A build up of H+ will make the muscle cells acidic and interfere with their operation so carrier molecules, called nicotinamide adenine dinucleotide (NAD+), remove the H+. The NAD+ is reduced to NADH that deposit the H+ at the electron transport gate (ETC) in the mitrochondria to be combined with oxygen to form water (H2O).

If there is insufficient oxygen then NADH cannot release the H+ and they build up in the cell. To prevent the rise in acidity pyruvic acid accepts H+ forming lactic acid that then dissociates into lactate and H+. Some of the lactate diffuses into the blood stream and takes some H+ with it as a way of reducing the H+ concentration in the muscle cell. The normal pH of the muscle cell is 7.1 but if the build up of H+ continues and pH is reduced to around 6.5 then muscle contraction may be impaired and the low pH will stimulate the free nerve endings in the muscle resulting in the perception of pain (the burn). This point is often measured as the lactic threshold or [anaerobic threshold](http://www.brianmac.co.uk/enduranc.htm#ant) (AT) or onset of blood lactate accumulation (OBLA).

The process of lactic acid removal takes approximately one hour, but this can be accelerated by undertaking an appropriate [cool down](http://www.brianmac.co.uk/warmup.htm) that ensures a rapid and continuous supply of oxygen to the muscles.

The normal amount of lactic acid circulating in the blood is about 1 to 2 millimoles/litre of blood. The onset of blood lactate accumulation (OBLA) occurs between 2 and 4 millimoles/litre of blood. In non athletes this point is about 50% to 60% [VO2 max](http://www.brianmac.co.uk/vo2max.htm) and in trained athletes around 70% to 80% VO2 max.

Reference: Disposal of Lactate during and after Strenuous Exercise in Humans, Journal of Applied Physiology, Vol 61(1), pp338-343, 1986

**Lactic acid - friend or foe?**

Lactic acid (lactate) is not:

* responsible for the burn in the leg muscles when exercising very fast
* responsible for the soreness you experience in the 48 hours following a hard session
* a waste product

Lactate, which is produced by the body all day long, is resynthesized by the liver (Cori Cycle) to form glucose that provides you with more energy. Sounds like a friend to me.

**Lactate Shuttle**

The lactate shuttle involves the following series of events:

* As we exercise pyruvate is formed
* When insufficient oxygen is available to breakdown the pyruvate then lactate is produced
* Lactate enters the surrounding muscle cells, tissue and blood
* The muscle cells and tissues receiving the lactate either breakdown the lactate to fuel (ATP) for immediate use or use it in the creation of glycogen
* The glycogen then remains in the cells until energy is required

65% of lactic acid is converted to carbon dioxide and water, 20% into glycogen, 10% into protein and 5% into glucose.

**Hydrogen ions**

The breakdown of glucose or glycogen produces lactate and hydrogen ions - for each lactate molecule, one hydrogen ion is formed. The presence of hydrogen ions, not lactate, makes the muscle acidic that will eventually halt muscle function. As hydrogen ion concentrations increase the blood and muscle become acidic. This acidic environment will slow down enzyme activity and ultimately the breakdown of glucose itself. Acidic muscles will aggravate associated nerve endings causing pain and increase irritation of the central nervous system. The athlete may become disorientated and feel nauseous.

**Aerobic Capacity**

Given that high levels of lactate/hydrogen ions will be detrimental to performance, one of the key reasons for endurance training is to enable the body to perform at a greater pace with a minimal amount of lactate. This can be done by long steady runs, which will develop the aerobic capacity by means of capillarisation (formation of more small blood vessels, thus enhancing oxygen transport to the muscles) and by creating greater efficiency in the heart and lungs. If the aerobic capacity is greater, it means there will be more oxygen available to the working muscles and this should delay the onset of lactic acid at a given work intensity.

**Anaerobic Threshold**

Lactic acid starts to accumulate in the muscles once you start operating above your [anaerobic threshold](http://www.brianmac.co.uk/hrm3.htm). This is normally somewhere between 80% and 90% of your [maximum heart rate](http://www.brianmac.co.uk/maxhr.htm) (MHR) in trained athletes.

**What a low Lactate Threshold means**

If your lactate threshold (LT) is reached at low exercise intensity, it often means that the "oxidative energy systems" in your muscles are not working very well. If they were performing at a high level, they would use oxygen to break lactate down to carbon dioxide and water, preventing lactate from pouring into the blood. If your LT is low, it may mean that:

* you are not getting enough oxygen inside your muscle cells
* you do not have adequate concentrations of the enzymes necessary to oxidize pyruvate at high rates
* you do not have enough mitochondria in your muscle cells
* your muscles, heart, and other tissues are not very good at extracting lactate from the blood

**Improving your Lactate Threshold**

The aim is to saturate the muscles in lactic acid in order to educate the body's buffering mechanism (alkaline) to deal with it more effectively. The accumulation of lactate in working skeletal muscles is associated with fatigue of this system after 50 to 60 seconds of maximal effort. Sessions should comprise of one to five repetitions (depends on the athlete's ability) with near to full recovery.

Training continuously at about 85 to 90% of your [maximum heart rate](http://www.brianmac.co.uk/maxhr.htm) for 20 to 25 minutes will improve your Lactate Threshold (LT).

A session should be conducted once a week and commence eight weeks before a major competition. This will help the muscle cells retain their alkaline buffering ability. Improving your LT will also improve your [tlimvVO2max](http://www.brianmac.co.uk/vvo2max.htm).

**Lactate Tolerance Training Sessions**

The following table identifies some possible training sessions that can be used to improve your lactate tolerance:

|  |  |  |  |
| --- | --- | --- | --- |
| Distance | Pace | Recovery | Reps |
| 150 metres | 400 metres | 90 seconds | 3 x 3 |
| 300 metres | 800 metres | 2 minutes | 6 |
| 150 metres | 800 metres | 45 seconds | 12 |
| 150 metres | 800 metres | 20 seconds | 2 x 4 |
| 300 metres | 1000 metres | 90 seconds | 9 |

**Sodium Bicarbonate**

Energy production via anaerobic glycolysis, which is particularly important for events lasting between 30 seconds and 15 minutes, increases the acidity inside the muscle cells and very soon after does the same to the blood. It is this increase in acidity, within the muscle cells, that is a major factor in producing fatigue. If there was some way to reduce the acidity within the muscle cells, one could theoretically delay fatigue and thus continue exercising at a very high intensity for longer.

Sodium bicarbonate is an alkalising agent and therefore reduces the acidity of the blood (known as a buffering action). By buffering acidity in the blood, bicarbonate may be able to draw more of the acid produced within the muscle cells out into the blood and thus reduce the level of acidity within the muscle cells themselves. This could delay the onset of fatigue.

**Who might benefit?**

The specific athletes who might stand to benefit from bicarb supplementation will typically compete in events that last between one and seven minutes, i.e. 400 metres to 1500 metres running, 100 metres to 400 metres swimming, most rowing competitions, and many team sports with their repeated nature of high intensity exercise which stresses the anaerobic glycolysis system significantly and produces a lot of acidity.

**A practical approach**

Before using either bicarbonate, it is wise to check with the governing body of your sport that the substance is not contrary to doping regulations. The most important practical point is the need to experiment with the supplement during training. Typically, an 800 metre runner, may perform a time trial on a particular day after a couple of days of light training. A further couple of days later, after only more light training, he/she can repeat the time trial in a similar environment after bicarbonate supplementation. The exact protocol would be to ingest 0.3 grms of sodium bicarbonate per kg body weight approximately one to two hours before the time trial. That is, for a 66kg runner, consume 20 grms of sodium bicarbonate (about four teaspoons) and, yes, the commonly found bicarb of soda is exactly the substance needed. This experimenting, if repeated several times, should reveal whether bicarb supplementation is likely to produce any benefit and whether the athlete concerned is susceptible to any side effects.

It is likely that large individual differences do exist as far as response to supplementation is concerned. It has been suggested that the more highly trained athletes are less likely to benefit from it because their body's natural buffering systems are already so well developed, but so far, this is just speculation. It has also been shown that sprinters build up more acidity within their muscles than endurance runners in response to the same exercise, and so may be more likely to benefit from the buffering effect. From the scientific research, it appears that the size of the dose is quite important, and that taking only 0.2 grms per kg is less likely to be beneficial than 0.3 grms per kg, although no evidence exists suggesting that an even greater dose is better still.

**Side effects**

As for the side effects, these may take the form of pain, cramping, diarrhoea or a feeling of being bloated. Drinking up to a litre of water with the dose is often effective and should be carried out as standard. Breaking up the bicarbonate dose into, say, four equal portions taken over the course of an hour may also help.

There are potential side effects to taking higher than normal levels of Sodium Bicarbonate so consult with your doctor first.

1. Explain why a build up of hydrogen ions in the muscle cells would cause your client to fatigue

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4 marks

1. List the three energy systems to produce energy to resynthesise ATP

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\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 3 marks

1. Define Lactate Threshold

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2 marks

1. Why would it be beneficial to create training programs to increase your client’s lactate tolerance levels?

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2 marks

1. If your client was aged 42, calculate the target rate for this person to train to improve their lactate threshold.

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1 mark

1. List and briefly explain 3 causes of muscle fatigue

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6 marks

1. List 2 symptoms that would help you and your client identify muscle fatigue

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2 marks